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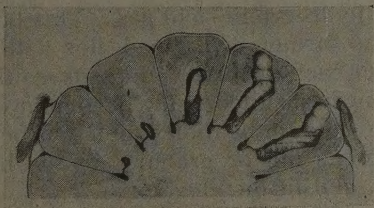
CONTROL OF INSECT PESTS IN STORED GRAIN



IT PAYS the farmer to harvest his grain crops as soon as possible after they have matured, and to fumigate promptly to kill any stored-grain insects.

Fumigation is most satisfactorily and economically conducted in tight cribs or bins, but should not be neglected if these are not at hand.

A number of fumigants are available for the control of stored-grain insects. Among these are carbon disulphide and mixtures of which it is the principal active ingredient, the ethylene dichloride-carbon tetrachloride mixture, carbon tetrachloride alone, ethylene oxide, and, under certain restricted conditions, hydrocyanic-acid gas. This bulletin will acquaint the farmer or grain dealer with the characteristics of each of these fumigants, so that he can select the one best suited to the particular conditions. It shows how the fumigation problem is being solved in the farmer's bin or granary, in the box car or ship's hold, and in the elevator.

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CONTROL OF INSECT PESTS IN STORED GRAIN

By E. A. Back, *Principal Entomologist, in charge*, and R. T. Cotton, *Senior Entomologist, Division of Stored-Product Insects, Bureau of Entomology*

CONTENTS

	Page
The problem serious, but can be solved	1
Spontaneous generation of grain insects a myth	2
Initial infestations occur in the field	3
Early fumigation profitable	6
When and where to fumigate	6
Common methods for controlling grain insects	6
Common heavier-than-air fumigants	15
Carbon disulphide	17
Carbon-disulphide mixtures	22
Ethylene dichloride-carbon tetrachloride mixture	23
Common heavier-than-air fumigants—Contd.	
Carbon tetrachloride	24
Ethylene oxide	24
How to fumigate with heavier-than-air gases	25
Hydrocyanic-acid gas	26
Odors following fumigation	28
Effect of fumigation on the germination of seeds	28
Heating grain and fumigation	28

THE PROBLEM SERIOUS, BUT CAN BE SOLVED

THE PROTECTION of grain in storage from insects is a serious problem for the farmer, grain dealer, and elevator man. The losses are tremendous. In a review in 1924 of the problems in marketing Pennsylvania wheat, it was estimated that during a recent outbreak of the Angoumois grain moth the State of Pennsylvania suffered an annual loss of from $1,000,000 to $3,000,000 from the depredations of this insect alone.

In 1912, when a survey was made of Alabama's crop of 54,000,000 bushels of corn, it was estimated that weevils cost the farmers of that State at least $4,000,000, and that was not an exceptional year. The loss of southern corn through insect attack ranges from 2 to 75 per cent. Unless protected in some manner, grain can not be produced in the South and held in storage until the summer following harvest without being rendered almost worthless. Corn arriving at our ports of entry from South America is often seriously damaged. Federal and State grain inspectors at all grain centers, such as Chicago, Kansas City, New Orleans, Minneapolis, Baltimore, and New York, can testify to the losses suffered by farmers in the form of discounts owing to the presence of weevils in wheat when it arrives at market from the farm.

Lack of knowledge of control methods causes many farmers to sell their newly harvested grain to escape depreciation due to insect attack, when they might treat it themselves at a slight cost and realize later good returns on advancing markets. Insects cause many persons to sell when the market is low, only to buy at a greater price grain shipped in from elsewhere when prices are high. An increasing number of farmers are protecting their crops and know that insect losses can be prevented once the crop is harvested and stored.

Treatment is not difficult. The results are immediate and visible. What the farmer or corporation with financial backing has found profitable the farmer with limited means will also find profitable. A desire to know the facts, a willingness to exercise ingenuity and thrift, and cooperation with a good county agent will result in many dollars saved.

SPONTANEOUS GENERATION OF GRAIN INSECTS A MYTH

The idea that insects develop from the "germ of grain" was exploded years ago, though it still persists among grain handlers and producers. This idea probably is the outgrowth of the fact that

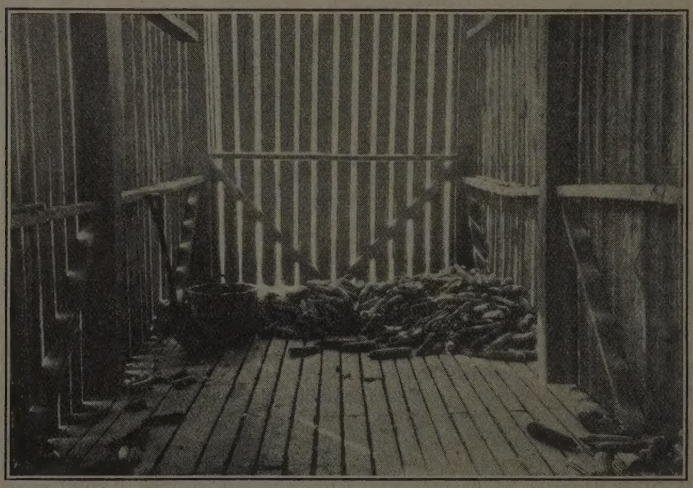

FIGURE 1.—Interior of a slatted corncrib on a Maryland farm. Such corn is usually more or less infested during the season after harvest with the Angoumois grain moth, and is the source of considerable infestation of ripening wheat. The adult moths fly from such corn to the wheat maturing in the field, where they lay eggs upon the wheat heads, thus starting an infestation that should be "nipped in the bud" by early harvesting and threshing. Sometimes as high as 2 per cent of the wheat kernels maturing in the field may be infested by the Angoumois grain moth developing in such cribs and flying to near-by fields

when grain is cold the insects present in it are so numbed that they can not feed. It is true that when the worst grain pests are very young they burrow into the kernel and grow by eating out the inside of the seed, but even an expert can not always be sure of infestation without using a microscope. Such insects in grain remain dormant during cold weather, but moderately high temperatures start them feeding; and if they all become fully grown at about the same time and eat their way out of the kernels, the owner will find his grain "weevil-cut" and alive with crawling weevils and may think that these weevils have developed spontaneously from the germ. In reality, however, they are the first clear external evidence of an infestation that, retarded by cold, has been waiting for the higher temperatures which would enable it to break out and spread.

INITIAL INFESTATIONS OCCUR IN THE FIELD

Many do not understand that our most serious pests of wheat, corn, and other cereals can fly and do not confine their attack to the harvested grain in granaries and elevators. Every farmer knows that the fag-end of the previous year's crop is always likely to be the portion most badly damaged by insects. What he doesn't realize is that the rice weevil and the Angoumois grain moth live over the winter in the grain in his bins, fly to the near-by fields of ripening wheat and corn as these are nearing maturity, and lay eggs upon the wheat heads or corn kernels. (Fig. 1.) These first infestations take place in the grain when it is in or passing the "milk" stage, and usually involve a very small percentage of all the kernels of the crop.

FIGURE 2.—Stack of unthreshed wheat on a Maryland farm. This wheat was still unthreshed by October following harvest. This condition favors insect infestation. Wheat threshed late after harvest in 1923 was often damaged from 60 to 90 per cent as compared with 1 to 2 per cent on neighboring farms where the crop was harvested and threshed promptly

In 1924 a study at harvest time of wheat-field conditions in Maryland showed that on an average 0.26 per cent of the kernels were infested by the Angoumois grain moth, and that on certain farms 2.06 per cent were infested. The 1922 examination of wheat in Montgomery County, Md., by the writers showed at harvest time an infestation of about 2 per cent by the Angoumois grain moth on certain farms. On other farms, where threshing had been delayed (fig. 2) until late September, the infestation by the Angoumois grain moth reached even 90 per cent.

In southern Georgia, in the first week of September, 1923, the examination by S. E. McClendon of 8,850 ears of corn taken from 21 farms showed 42.9 per cent of the ears already more or less

infested by the rice weevil before these particular fields were ready to harvest. A careful examination of one lot of 25 ears broken from the stalks showed that 13 carried rice weevils, and that on these 13 ears the weevils numbered 51, 34, 8, 11, 23, 13, 12, 8, 2, 4, 34, 113, and 5 individuals, respectively. An examination in one field made in late September, 1925, by McClendon and the senior writer indicated that fully 95 per cent of the ears were infested by the rice weevil. At Sanford, Fla., rice weevils have been found infesting corn in the milk stage as early as May.

Of the total number of inspections made in Oklahoma of wheat arriving at market from the farms from September 3, 1919, to December 31, 1919, the percentages of carloads reported infested by rice weevils and Angoumois grain moths for each of the 17 weeks beginning with the week of September 3 were 17, 30, 55, 44, 69, 69, 78, 88, 75, 90, 82, 66, 67, 63, 80, 75, and 58 per cent, respectively.

FIGURE 3.—Corncrib made of hollow tile. It is 16 feet in diameter and 14 feet high and cost $332. An experienced fumigator states that this is one of the tightest cribs in southern Georgia

Of the carload lots of wheat and corn received at Sherman, Tex., during the months of July to December, 1920, 88.7 per cent of the wheat and 79.5 per cent of the corn were found infested by the rice weevil and the Angoumois grain moth.

The inspection certificates of winter wheat shipped into the Baltimore market from July 1, 1922, to June 30, 1924, showed that 13 per cent of the 7,892 carloads were graded "sample grade" during the season 1922–23 on account of the presence of insects, and 20 per cent of 2,860 carloads during the season 1923–24. Wheat arriving on the Baltimore market is drawn from Pennsylvania, Maryland, Delaware, Virginia, and West Virginia. The receipts of winter wheat in 1922–23 amounted to about one-third of the marketed crop, or one-fifth of the estimated crop of these five States. The rather high percentage of infested cars was due to an outbreak of the Angoumois grain moth which occurred in this region in the years 1921, 1922,

and 1923. The outbreak subsided in 1924, with the result that inspection certificates of winter wheat arriving on the Baltimore market from July to November, 1924, showed that of 2,008 cars inspected only 4 per cent were infested with insects. This is probably more nearly representative of the condition of all marketed wheat in years when there are no serious outbreaks of grain pests, for according to experts of the Bureau of Agricultural Economics, United States Department of Agriculture, a survey of inspection reports for the four years from July 1, 1917, to June 30, 1921, showed that 5 per cent of all wheat which moved in interstate commerce was graded sample grade.

These few definite instances of grain infestation for the the period from just before harvest to the time the grain arrives at the central

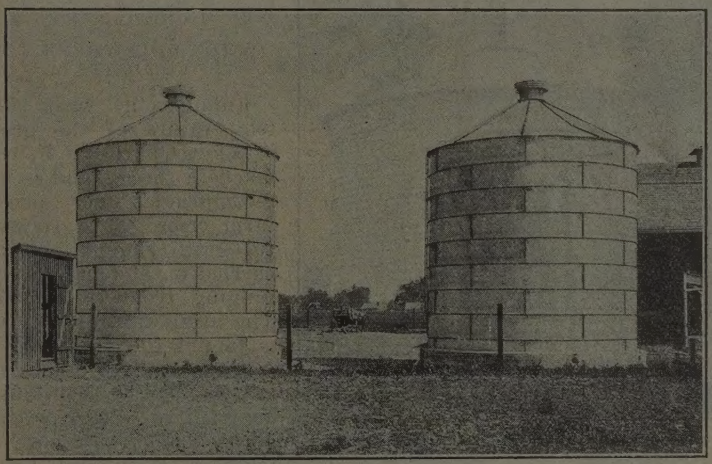

FIGURE 4.—Galvanized-iron corncribs on large modern dairy farm at Donaldsonville, La. Choice dent corn has been stored in these containers for about 15 years and protected by fumigation with carbon disulphide. These cribs stand in the barnyard, a few feet away from a modern dairy barn. They are 18 feet in diameter, 17½ feet high, and estimated to hold about 500 bushels of shucked corn. The ventilator outlets at base and the doors are sealed during fumigation. These are wonderfully tight cribs for protecting grain by fumigation

grain market in the fall of the year of harvest emphasize the fact that nearly all grain crops, except in the extreme North, are usually already somewhat infested when ripe for harvest, and that delays in getting the crop under cover and into bins where it can be treated, if necessary, offer the insects opportunity to multiply and infest other kernels. The insects present in any properly harvested crop are relatively a very small number compared with those developed later, and each day's delay in treatment increases their number tremendously. Since few fumigations can be so thorough as to kill all insects in the grain, the farmer gets by far the best results when he fumigates his crop directly after harvest, when the insects are at their numerical minimum and before they have had a chance to cut many kernels. In short, it pays from an insect-damage standpoint to harvest as soon as possible after the crop has matured, and to treat as soon as possible thereafter to kill any insects in the crop.

EARLY FUMIGATION PROFITABLE

Insect damage to grain is not particularly noticeable until the insect developing within the kernel matures and eats its way out, thus leaving a hole that classifies the kernel as "weevil cut." When a grower finds insects already attacking his grain at harvest time, it is money in his pocket to fumigate promptly. It is easier and more profitable to control insects when they are few than to wait until they are noticeably abundant. If the insect grub developing within the kernel is killed before it has a chance to develop, serious losses will be avoided. It is much more profitable to fumigate early and successfully than to send infested grain to the elevator or mill and get a lower price.

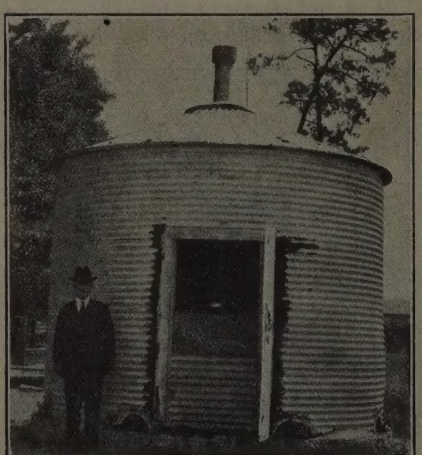

FIGURE 5.—Galvanized-iron corncribs are proving satisfactory when well set up. This one has just been fumigated with carbon disulphide. The door and ventilators at bottom had been sealed by applying clay mud instead of gummed paper. Results are very good in these relatively cheap cribs. This owner poured his fumigant into shallow dishes set on the grain

WHEN AND WHERE TO FUMIGATE

Fumigation when the temperature of the grain is below 60° to 65° F. will not be a success and is not recommended for most farm cribs. Most successful grain fumigations are carried on at temperatures ranging from 75° to 95°. The ideal way to fumigate is to put the grain into a very tight bin or other container. The best containers are made of metal or concrete. Excellent cribs for treating grain are being constructed of brick, hollow tile (fig. 3), concrete, galvanized iron (figs. 4 and 5), steel and wood (figs. 6, 7, and 8). Even a dry-goods box (fig. 9) can be made tight enough by lining it with several thicknesses of heavy paper. Grain piled on the ground (fig. 10) can be fumigated with fair results if covered properly with a good tarpaulin.

Read the legends of the accompanying illustrations (figs. 3 to 21) for a better idea of conditions under which grain is being fumigated to-day. Ingenuity, initiative, and a small outlay of money will make it possible to convert loosely constructed grain bins into places where grain can be fumigated successfully. Your county agent, State or Federal Department of Agriculture, or your own engineers, in the case of elevators, can help you solve your problems.

COMMON METHODS FOR CONTROLLING GRAIN INSECTS

Aside from early harvesting and threshing of grain, which lessen the chances for insects to attack grain seriously, the most common

method employed for killing insects in bulk grain is fumigation. This is the only method at present available on the average farm. At grain elevators many insects can be removed by the running,

FIGURE 6.—Corncribs at Glen Saint Mary Stock Farm, Glen Saint Mary, Fla., planned and built by H. H. Hume. These cribs are of tongue-and-groove material, with building paper between. They have given satisfaction from the standpoint of corn storage and fumigation for nearly 15 years

screening, and blowing processes; but even this moving of the grain does not remove the kernels in which small grubs are developing, nor does it get rid of all of the other insects. Running the grain

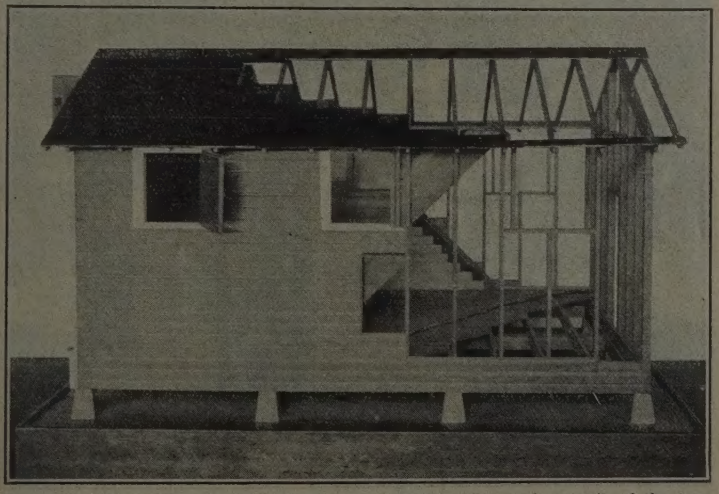

FIGURE 7.—Model showing the method of construction of a good corncrib of the type shown in Figure 6

from one elevator bin to another in cold weather and allowing the grain to fall through the air in zero weather will cool the grain, and if this is cooled to a sufficiently low temperature insect activity

FIGURE 8.—Corn grown in the Gulf Coast States is usually rendered unfit for animal food by June or July following harvest if it is not protected from insects. Above is shown a crib of corn in August following harvest still in prime condition and being used as food for poultry and hogs. The missionary work of the United States Department of Agriculture has resulted in hundreds of such good cribs being built in southern Georgia

FIGURE 9.—This boy on a small Orlando (Fla.) farm did not have the money to build proper storage for his small corn crop. Yet he won a scholarship at the University of Florida by raising the best pig in his county, feeding it corn that had been protected from weevils by fumigation with carbon disulphide. He was enterprising enough to get dry-goods boxes from a town store and make them into good fumigating boxes by lining them with several thicknesses of good paper. A little initiative and ingenuity solves many a problem inexpensively

will cease for varying periods, depending upon the opportunity for the grain again to become warmed.

Heating grain to a temperature of 125° to 140° F. in grain driers will kill all insects within the grain, provided each kernel is thoroughly heated through to these temperatures. Heat is used

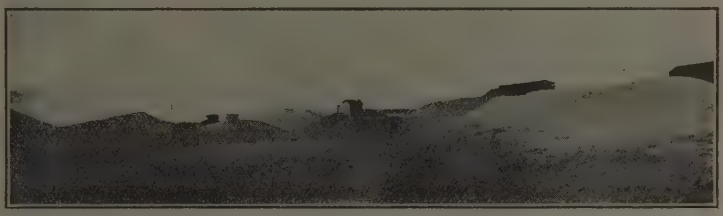

FIGURE 10.—Thousands of bushels of wheat, rye, and kafir piled on the ground at Hugston, Kans., for lack of cars, March, 1923. Grain stored in this manner or in sacks stacked out of doors can be fumigated with fair results if the fumigated portion is covered well with tarpaulins. The tarpaulins must extend out over the ground around the pile fumigated and should have dirt shoveled over the edges to aid in confining the gas. Carbon disulphide is the best fumigant for this type of fumigation

FIGURE 11.—A satisfactory corncrib built by an enterprising farmer of Waycross, Ga. This was formerly a slatted crib that could not be fumigated. The floor was tightened and the walls covered with heavy building paper and a layer of tongue-and-groove boarding. Corn has been protected from weevils by fumigation in this crib for over five years

successfully in sterilizing grain at ports of entry where it is desired to prevent the entry of foreign pests. All modern and large elevators are equipped with heating and drying equipment (fig. 22), but this equipment is used primarily for controlling the moisture content of grain. Since grain in the United States is bought and sold by

FIGURE 12.—Two typical Georgia barns into which have been built compartments for storing corn where it can be treated successfully with carbon disulphide or any other satisfactory fumigant

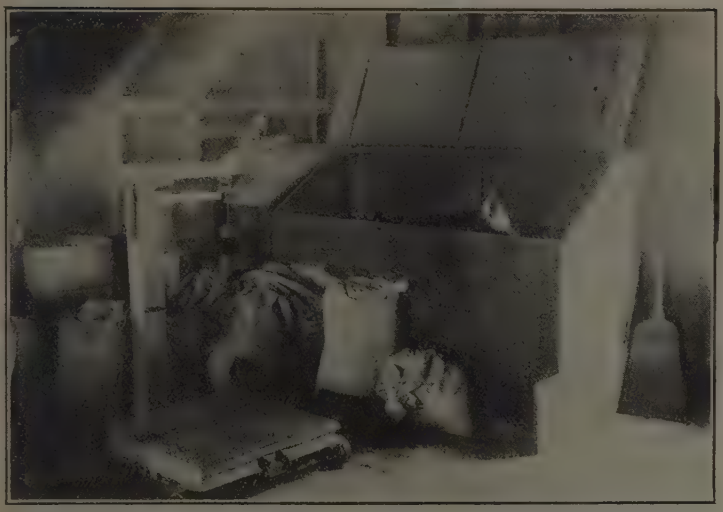

FIGURE 13.—The corner of a feed room as shown above is a common sight on farms. Such feed boxes can be built tightly and used on occasion for fumigating grain. Pour the fumigant directly on the grain or into shallow dishes placed on the grain; cover all well with old sacks and close and seal the cover

FIGURE 14.—Corn, protected by fumigation, is depended upon by progressive cattle breeders in the South to furnish high-grade food throughout the year. In the large crib in the left foreground in the lower picture carbon disulphide has been used for years with excellent results. Note proximity of crib to other farm buildings. Cattle raised on this Thomasville (Ga.) farm take prizes at the stock shows in Chicago

FIGURE 15.—A typical Maryland barn, with stables in basement. The wheat bin shown in Figure 16 is built into the right-hand far corner on the first floor above the stables. It is made of two thicknesses of tongue-and-groove material with building paper between and is so tightly constructed that wheat placed in it has been fumigated with carbon disulphide without the odor penetrating to the stables beneath. With so much hay and wheat straw about, the farmer must exercise great caution to keep fire in any form away from the barn during the period of fumigation. It would be safer under these conditions to use a noninflammable and nonexplosive fumigant

FIGURE 16.—Grain bin on wagon floor of barn shown in Figure 15. Wheat in this well-built bin has been fumigated successfully for some years with carbon disulphide. The farmer recognizes the danger of fire when carbon disulphide is used and allows no one near the barn during fumigation

FIGURE 17.—The management of Raceland Plantation, Raceland, La., says that carbon disulphide fumigation has solved their "weevil problem." Some years ago this was one of three chief problems involving loss on this great sugar plantation. By spending about $500 in tightening their old crib, two aspects of which are shown above, and by fumigating with carbon disulphide, they claim (1929), after fumigating for over 12 years, that they save yearly at least 3,000 bushels of corn. The crib is 35 by 85 by 16 feet and holds approximately 12,500 bushels of shucked corn. It was tightened by sealing with ordinary tongue-and-groove boards *well driven together*. The crib is filled by means of a corn elevator hopper spout taking corn into the building through the door in the gable and placing it in the crib through openings in top of crib. About 500 pounds of carbon disulphide is used to a treatment, this being poured in through the 15 manholes in top of crib by men entering through door in gable. A, Building filled and closed for fumigation; B, crib emptied, with end doors open.

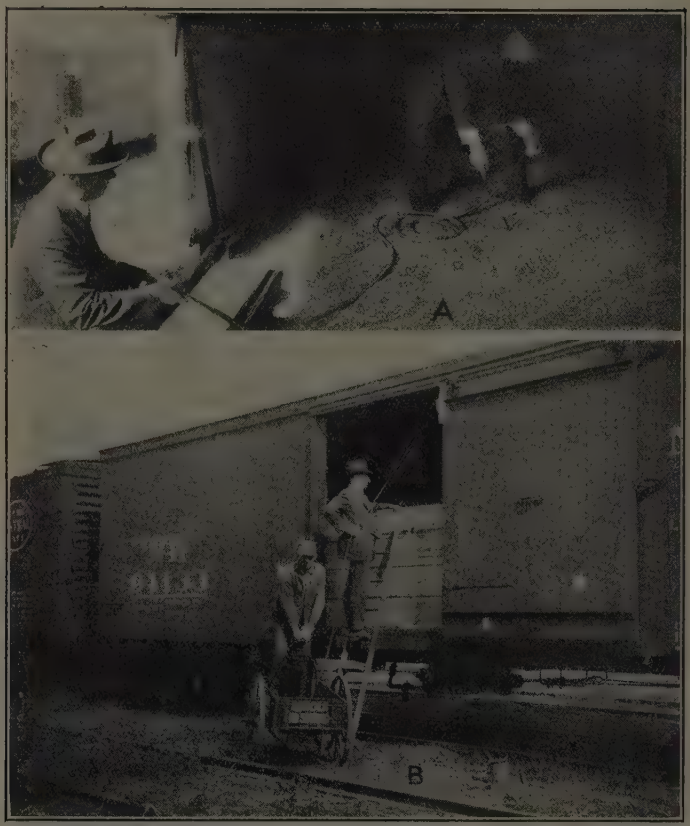

FIGURE 18.—Grain arriving at elevator after shipment from farm. If such grain shows the presence of even a few live adult weevils it is sample graded and this may greatly reduce its value. If the grain is not so badly "cut" by insects but that it would be grade No. 1 were no live adult insects present, it can be graded No. 1 if the insects are killed by fumigation. Treatment to restore it to this grade costs the farmer about 2 cents per bushel when carbon disulphide is used; of this amount one-half cent is charged to fumigation with carbon disulphide. Many cars are fumigated. Above, the manager of an elevator at Baltimore, Md., is shown applying carbon disulphide or any liquid heavier-than-air fumigant. In this instance, the carbon disulphide, carried on the push cart in a metal tank, is pumped through a rubber hose into a perforated brass rod inserted into the grain. It is doubtful whether this method of application has advantages over simply pouring or sprinkling the liquid on the grain

weight, and since heating grain reduces the weight by driving off some of the moisture content, heat is not a favorite control measure for insects at grain elevators.

Aside from the application of heat and cold and other elevator practices, all who are interested in insect control in grain are forced to recognize the importance of control by fumigating grain in suitable tight containers. For farm use the only fumigants satisfactory at the present time are those that can be depended upon to penetrate bulks of grain as ordinarily stored. Such fumigants are heavier-than-air gases. The lighter-than-air fumigants, notably hydrocyanic-acid gas, are seldom used for fumigating grain in bulk, since these gases do not penetrate very deeply into masses of grain. This is true also of the heavier-than-air gas, sulphur dioxide, which in addition destroys the germinating power of seeds and injures the baking quality of the flour made from fumigated wheat.[1]

FIGURE 19.—A cribbed elevator typical of many country elevators. One bin 10 by 10 feet and 42 feet deep, filled to capacity with shelled corn, was fumigated with carbon disulphide in September, 1920, by pouring the liquid directly on top of the corn. Examination 12 hours later of samples of badly infested corn in sacks tied to the supporting iron rods and in the concrete base before the bin was filled, showed all weevils dead. Some weevils in samples tied to ladder, near cracks in the wooden walls, were not killed—another argument for tightness to secure best results. The death of the weevils in the bottom of the bin answers the question often asked if carbon-disulphide gas will penetrate shelled corn. Only noninflammable and nonexplosive gas should be used in these elevators. It is difficult to keep smokers away from such country elevators

For use in grain elevators, a method has been perfected for successfully fumigating grain by introducing a form of calcium cyanide into the stream of wheat as the grain enters the bin. This highly specialized method of treatment is available at present only for the large storage elevators. For further information see page 27.

The ethyl-acetate-carbon tetrachloride mixture, discussed in the first edition of this bulletin, is no longer recommended because of its unpopularity due to persistent odor following its use under certain conditions.

COMMON HEAVIER-THAN-AIR FUMIGANTS

The expression "heavier-than-air fumigants" means those gases that, being heavier than air, will sink down into the grain in a tight

[1] Sulphur dioxide was once used extensively for fumigation of grain in ships. By a patented process the fumes were forced through the grain. It is not now used in the United States as a grain fumigant.

bin and, by forcing the lighter air out, will smother and kill all insects within the bin. In thoroughly tight bins these gases can kill all stages of the insects—the adult insects crawling between the kernels, the eggs already laid in the kernels, and the grubs, pupae, and adults

FIGURE 20.—Wheat and corn grown on the farms arrive at grain elevators in large distributing and exporting centers in railroad cars as shown above. The grain is usually in bulk, though sometimes sacked. Railroad officials have prohibited, except at certain points, the use of carbon disulphide as a fumigant for treating grain in rolling stock, in spite of its excellence as a fumigant and the negligible number of accidents that have followed its use over a period of many years. Fortunately the ethylene dichloride-carbon tetrachloride mixture or certain carbon-disulphide mixtures approved by fire underwriters can be used effectively in these grain cars. The average box car has a capacity of 2,750 cubic feet and contains on an average about 1,300 bushels of wheat

within the kernels themselves. If bins are not thoroughly tight the effectiveness of the gases is reduced in proportion to the opportunities given the gas for escaping through cracks or other openings (figs. 23 to 26) in the bottom and sides of the bin, or being dissipated somewhat at open tops.

At present there are a number of heavier-than-air chemical fumigants that offer a safe control for insects under storage conditions. These are carbon disulphide and certain carbon-disulphide mixtures, ethylene dichloride-carbon tetrachloride mixture, carbon tetrachloride alone, and ethylene oxide. The farmer and grain dealer should become acquainted with the characteristics of each of these fumigants and select the one best suited to the particular conditions.

Chloropicrin, one of the powerful war gases, shows promise of becoming a practical fumigant for bulk grain, but has only recently become commercially available.

Ethylene oxide has proved an excellent and safe fumigant under certain conditions, but its availibility for bulk-grain fumigation has not yet been fully demonstrated. For further discussion of ethylene oxide as a fumigant for bulk grain see page 24.

FIGURE 21.—A ship being loaded with wheat at a Galveston, Tex., elevator. The problem of furnishing grain containing fewer insects has been made easier by the discovery of a noninflammable and nonexplosive fumigant which can be used with safety at elevators and about shipping equipment

CARBON DISULPHIDE

Carbon disulphide has been in use for years as a standard and successful fumigant for grain. It is a highly inflammable liquid. It will not only flash but continue to burn at a temperature as low as −4° F. The greatest danger with this substance resides in the volatility of its inflammable vapors, which form explosive mixtures with air, and its tendency to ignite spontaneously when heated to about 300°, or in the presence of iron and other metals, particularly copper, at a much lower temperature. In the presence of copper it ignites at as low a temperature as 205°. Six per cent of the vapor of carbon disulphide in air makes an explosive mixture, and the presence of dusty, metallic surfaces (such as are present in mills and elevators) favors the explosibility of the vapor. Because of the fire hazard involved in the use of carbon disulphide, most insurance companies prohibit its use in buildings covered by their

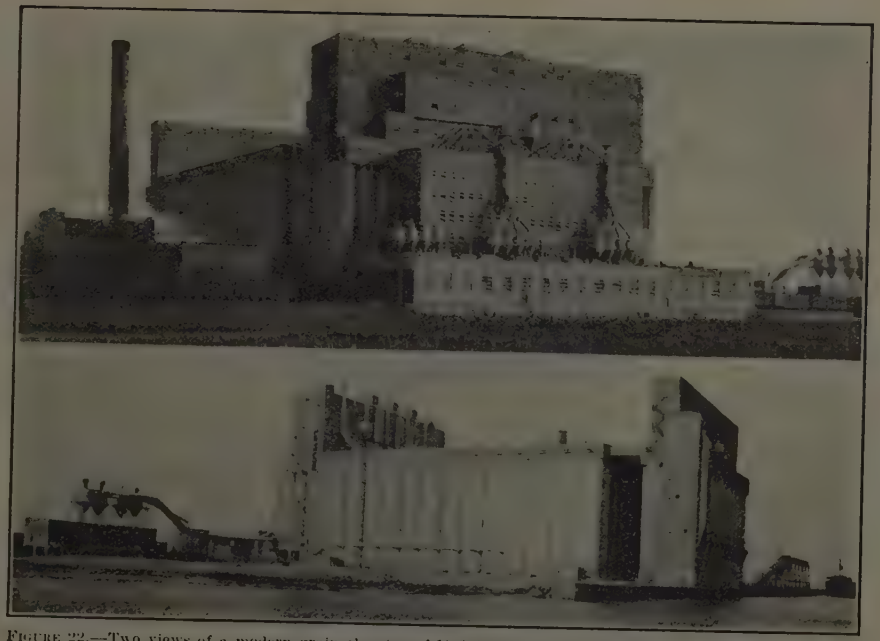

FIGURE 22.—Two views of a modern grain elevator of 10,000,000 bushels capacity. Such elevators can not afford to use inflammable or explosive fumigants in their bins. The highly technical method of introducing calcium cyanide into the stream of wheat as the grain enters the bin has been proved satisfactory from the standpoint of killing insects without entailing a fire or explosion hazard. Only an experienced operator should attempt this specialized control method, which is discussed on page 27. Note evidence of equipment for drying and heating grain. It is possible to dry and heat grain to kill insects whenever such treatment is considered practical from a business standpoint

FIGURE 23.—A typical "pole" crib found on farms throughout the South. Corn stored in such cribs can not be fumigated satisfactorily

policies, except in certain cases where its use is permitted under conditions imposed by the insurance companies.

Many attempts have been made to prepare a fumigant containing carbon disulphide that would be free from the fire hazard. Several such mixtures have been approved by the fire underwriters and can be obtained commercially. The usefulness of these mixtures is discussed on page 22.

Carbon disulphide gas explosive and inflammable.—In spite of the explosive and inflammable nature of the gas, it must be admitted that, considering the large quantity of carbon disulphide used for years past, the number of fires and explosions resulting from its use has been exceedingly small, and these few have always been traced to carelessness. Many owners of small elevators throughout the Middle West state that they have been using carbon disulphide so satis-

FIGURE 24.—Perforated galvanized-iron corncrib installed on dairy farm in Georgia. Such perforated cribs have little to commend them from the standpoint of weevil control. They can not be fumigated without putting a tent over them. (See fig. 25)

FIGURE 25.—A perforated galvanized corncrib covered with a tent during fumigation. Such cribs are difficult to cover and can not be very effectively fumigated. There is great opportunity for the escape of the gas

FIGURE 26.—Wheat and corn are often stored in very old and very loosely constructed barns not fitted for fumigation. Above is shown a wheat bin in such a barn. If an emergency arises and the bin can not be tightened because of labor shortage or lack of funds, many of the weevils can be killed by pouring the fumigant directly upon the grain and covering the surface of the grain at once with tarpaulins, empty sacks, bed quilts, etc. There will be much leakage of gas through the floor, but the wheat itself has a tendency to hold the gas. Before fumigation the grain should be shoveled into as compact a mass as possible

factorily for years that they are going to continue its use. Plantation managers and progressive farmers of the Gulf Coast States have found in carbon disulphide an almost perfect fumigant for protecting corn from weevils. Large elevators in Baltimore, Md., are still using large quantities of carbon disulphide in fumigating grain in railway cars. These statements are made in order that one may not be frightened away from the use of a cheap and effective fumigant merely because it must be handled carefully. The writers seldom recommend carbon disulphide for fumigating large buildings; but for the average grain bin or crib, or the small elevator where surrounding conditions can be controlled, this gas has no

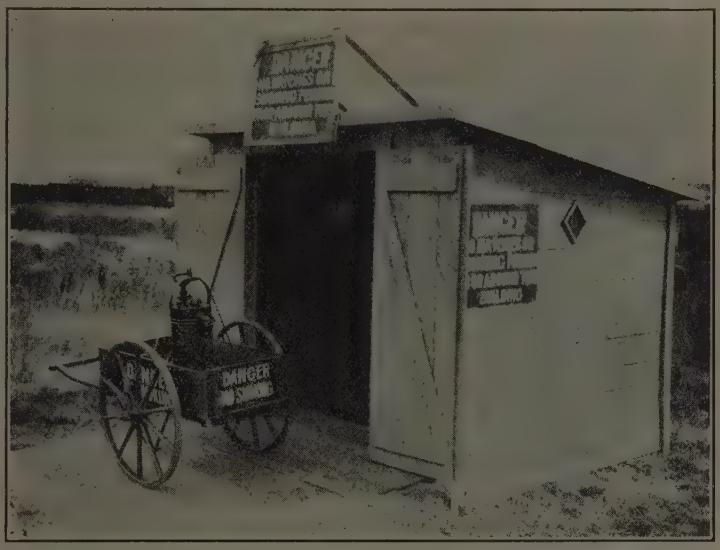

FIGURE 27.—A method of storing and carrying carbon disulphide used by a Maryland elevator. The shed contains the drums of liquid. Needed amounts are transferred to the tank mounted on the cart. One man can push the cart to the place of fumigation

superior from the standpoint of toxicity under average conditions prevailing at the present writing (October, 1929). For fumigating large elevator bins, or when there is the least danger from fire in any form, a noninflammable fumigant should be used.

Remember, lighted lanterns, sparks from electric switches, sparks formed by hammering upon metals, lighted cigars, a stove fire in a cook's quarters on a grain boat, even hot steam pipes and static and frictional electricity, may cause an explosion of carbon disulphide vapor; therefore fire in any form, or excessive heat, or frictional or static electricity should not be allowed near a bin or building that is being fumigated with this chemical.

Carbon disulphide liquid will boil at 115° F., which is about the highest temperature of water in which the hand can be held. The supply of this fumigant should therefore be kept under cover and protected from fires and the heat of the sun (figs. 27 and 28). The

liquid weighs about 10½ pounds per gallon at ordinary temperatures. Since many complaints are made of the poor quality of certain grades of carbon disulphide placed on the market, it pays to buy from reliable sources and get good grades.

One volume of carbon disulphide on evaporating can produce 375 volumes of vapor or gas. This gas is 2.63 times as heavy as air. Being heavier than air, it sinks down through the grain, displacing the air, and if the bin is tight enough forms a sufficient concentration to kill all stages of the insects in the grain.

Dose to use.—In a thoroughly tight container 4 pounds of carbon disulphide per 1,000 cubic feet of space, regardless of the amount of this space occupied by the grain, will kill all insects. In the average well-built cornerib, designed especially for fumigation, 8 pounds per 1,000 cubic feet of space is the more common dosage. In many more ordinary cribs as high as 20 pounds per 1,000 cubic feet is used. As grain is valuable and the fumigant is relatively cheap, it is better to use more than is actually necessary and kill the insects than to overestimate the tightness of the crib and use too little and have to do the job all over again. A few fumigations will acquaint each man with the dosage the particular crib needs.

FIGURE 28.—Shelter showing how one large concern using much carbon disulphide for fumigating grain stores its drums of the fumigant away from buildings and out of the direct rays of the sun

Effects of breathing the gas.—The breathing of carbon disulphide vapor in excess produces giddiness, and occasionally vomiting, and has a peculiarly benumbing effect upon the senses. The action of the vapor is somewhat poisonous as well as suffocating, and it is dangerous for persons having weak hearts to take an extended part in fumigating operations. Fumigators should inhale as little of the fumigant as possible, and seek the fresh air as soon as its bad effects begin to be noticed.

Cost.—The cost of carbon disulphide varies in different sections of the country. In general, when purchased in 1-pound tins the price ranges from 25 to 45 cents; when purchased in 500-pound drums (fig. 29) it should not cost more than 6 cents per pound f. o. b. factory at present market prices.

CARBON-DISULPHIDE MIXTURES

Mixtures of carbon disulphide and carbon tetrachloride are now being used rather extensively for grain fumigation in certain sections of the country. These mixtures consist of small percentages of carbon disulphide in carbon tetrachloride to which may be added a

small quantity of sulphur dioxide or other chemicals. When properly made such mixtures appear to be relatively free from fire hazard and are being sold apparently with the approval of the board of underwriters.

It is not advisable for the layman to attempt the manufacture of such mixtures since the safety of the fumigant is dependent upon its proper preparation. The efficacy of such a fumigant is directly proportional to the quantity of carbon disulphide it contains, and should be used accordingly. That is a mixture containing 20 per cent of carbon disulphide is about one-fifth as effective as the pure carbon disulphide. Mixtures containing only 2 to 6 per cent of carbon disulphide have not given satisfactory results when used as the rate

FIGURE 29.—If carbon disulphide or any other fumigant such as carbon tetrachloride or ethylene dichloride-carbon tetrachloride is purchased in drums through community effort for distribution by county agents, the drum should be mounted so that the liquid can be drawn off through a faucet. The drum should be protected from the bright sun. If the fumigant is poured from the bunghole in small lots at different times, much will be lost

of one gallon per thousand bushels of wheat in railroad cars and in cribbed elevators with open tops.

For ordinary fumigation work the methods described for the use of carbon disulphide will apply equally well for these carbon disulphide-carbon tetrachloride-sulphur dioxide mixtures. For use in tight bins in elevators the method devised by Schenk for the application of calcium cyanide (see p. 27) appears to give the most satisfactory results. By means of a special hopper, the mixture is fed into the grain stream as the bin is filled. The hopper is regulated to apply approximately 10 pounds of the mixture to each 1,000 bushels of grain.

ETHYLENE DICHLORIDE-CARBON TETRACHLORIDE MIXTURE

The ethylene dichloride-carbon tetrachloride mixture is an inexpensive, noninflammable fumigant that can be used with safety in situations where it is unwise to use carbon disulphide. It is

made of 3 parts by volume of ethylene dichloride and 1 part by volume of carbon tetrachloride. It can be purchased already mixed, or the user can obtain the two chemicals and combine them himself.

The ethylene dichloride is the active ingredient of the mixture, the carbon tetrachloride being used to render the fumigant noninflammable. The ethylene dichloride is a colorless liquid with an odor resembling that of chloroform. It is about one and one-fourth times as heavy as water, 1 gallon weighing 10.4 pounds. Its vapor is over three times as heavy as air.

It should be applied in the same manner as carbon disulphide or the carbon-disulphide mixtures. It is about one-fifth as toxic against the rice weevil as carbon disulphide and should be used accordingly.

It has no adverse effect upon the germination of seeds and is not dangerous to handle. It has an anæsthetic action when breathed in concentrated form, but unless the fumes are breathed for a protracted period no harmful results need be feared.

The ethylene dichloride-carbon tetrachloride mixture costs about 10 cents per pound.

CARBON TETRACHLORIDE

Carbon tetrachloride is a thin, transparent, colorless liquid, in appearance similar to water. The gas formed by its evaporation has a pungent aromatic odor. It should never be used at temperatures lower than 70° F., as fumigants are seldom very effective unless the insects treated are in an active state.

Carbon tetrachloride is not so effective a grain fumigant as the other fumigants mentioned above. It has one great advantage over carbon disulphide in that the gas formed by its evaporation is noninflammable and nonexplosive in the presence of fire. It is itself a fire extinguisher. Until the more effective noninflammable and nonexplosive fumigants were developed, carbon tetrachloride was the only fumigant generally used for grain fumigation where carbon disulphide could not be used because of the fire hazard. In spite of this fact grain men with experience have come to believe that carbon tetrachloride alone is not a dependable grain fumigant except perhaps, in very tight containers. It evaporates slowly and its action is poor in cool weather that is still warm enough for good results if carbon disulphide is used. In general, it is believed by the writers to be about one-twentieth as effective as carbon disulphide when used under favorable conditions. Since it must be used in correspondingly larger doses to get approximately the same results and costs about the same per pound, fumigation with carbon tetrachloride is considerably more expensive than fumigation with carbon disulphide. Carbon tetrachloride is a safe fumigant, but should be selected only as a last resort.

ETHYLENE OXIDE

Ethylene oxide, a gas recently developed by the Bureau of Entomology in cooperation with the Bureau of Chemistry and Soils, shows promise of being an excellent fumigant for stored grain when used in combination with carbon dioxide.

Preliminary tests indicate that satisfactory results can be obtained in large storage tanks without hazard from fire, or danger to the operator, and at a reasonable cost.

Ethylene oxide at ordinary temperatures is a colorless gas. At low temperatures it is a mobile, colorless liquid boiling at 10.5° C. (about 51.4° F.) and having a specific gravity of 0.887 at from 4° to 7° C. (about 39.2° to 44.6° F.). The concentrated vapors of ethylene oxide are inflammable, but concentrations up to 3½ pounds per 1,000 cubic feet of space are nonexplosive and noninflammable. The ignition point is 814° F. The gas is not highly toxic to man, but when inhaled for a long time produces a cyanosis, which, however, is counteracted by the use of carbon dioxide as an antidote.

The use of carbon dioxide in combination with ethylene oxide in the proportion of 7 parts by weight of carbon dioxide to 1 part of ethylene oxide greatly increases its insecticidal action and in addition entirely removes any possibility of fire. For this reason it is always desirable to use carbon dioxide with ethylene oxide.

A dosage of 2 pounds of ethylene oxide per 1,000 cubic feet of space fumigated, with the carbon dioxide in proportion, appears to be satisfactory.

Methods of applying the mixture to the grain are still in the experimental stage, but it is hoped that they will be perfected in the near future. Ethylene oxide can be purchased at a cost of 75 cents per pound.

HOW TO FUMIGATE WITH HEAVIER-THAN-AIR GASES

Carbon disulphide, carbon disulphide mixtures, carbon tetrachloride, and the ethlylene dichloride-carbon tetrachloride mixture may be purchased as liquids, shipped in tin cans or steel drums. They are most expensive when bought in 1-pound tin cans and cheapest when bought in the larger steel drums. (Fig. 29.)

To fumigate successfully remember that—

(1) **The bin must be tight.** A wooden bin is seldom tight enough unless it is built of two thicknesses of tongue-and-groove material well driven together, with heavy building paper between the layers. This applies to the floor as well. Take extra care with corners where walls join walls and the floor. (Fig. 7.) Each crack will allow the gas to escape. The more gas that escapes the less effective the fumigation. The gas must be confined well with the grain if it is to kill the insects.

(2) **The grain must be warm enough.** Never fumigate when the grain temperatures are lower than 60° to 65° F. Fumigate preferably at temperatures above 70° or 75°. Results are usually better in ordinary bins with temperatures between 80° and 95°.

(3) **The bin door must be tight and sealed.** Watch the granary door. The average door is so loosely closed that much gas escapes around it. A door of refrigerator type is best. Always seal the door after applying the fumigant. Do this by pasting good paper over the cracks or rubbing clay mud into the cracks. Several thicknesses of newspaper applied with a homemade flour paste will serve the purpose. The door is often a very poorly made or poorly fitted part of an otherwise excellent crib.

(4) The fumigant should be applied by removing it from the original container. Just before closing and sealing the door, pour or sprinkle the necessary quantity of liquid over the top of the grain. If the bin is tight enough to hold the gas that forms, it does not make much difference how the liquid is applied. The fumigant may be applied by pouring it into shallow dishes like pie tins or soup plates resting on top of the grain. Some persons merely pour the liquid over the top of the grain from a water pail. Others insist on sprinkling it on the grain from a flower-watering pot. The writers usually pour the fumigant with a sweeping movement from a water pail or from the original container, provided the container does not hold more than 5 gallons. They have fumigated 50-foot elevator bins successfully with carbon disulphide by merely pouring the liquid over the top of the grain. (For one method of introducing the liquid into the grain see fig. 30 and legend.) Do not pour all the liquid in one spot, and do not expect to succeed by burying the liquid in the grain in its original container with the cork taken out. Some persons think that a slow evaporation of the liquid will give best results. This is not so. *Try to get a rapid evaporation of the liquid, so that a strong concentration of the gas is formed quickly.*

FIGURE 30.—In fumigating a farmer's bin either pour the fumigant into shallow dishes as shown above or pour it directly upon the grain. Do not expect results if you bury the cans of liquid upright in the grain. Never expect results by placing the uncorked container in the bottom of the empty bin before filling the bin with grain. The walls of the bin shown are of a single thickness of tongue-and-groove material and are not well made for confining the gas. Leave the bin promptly after pouring out the liquid, to avoid breathing an excessive amount of the gas

(5) It is always best to cover with a tarpaulin or with sacks the surface of the grain being fumigated. This aids in holding the gas long enough to kill the insects.

(6) The breathing of an excessive quantity of these fumigants should be avoided, and persons having any trouble or weakness of the heart should take no extended part in the application of carbon disulphide.

HYDROCYANIC-ACID GAS

The successful use of hydrocyanic-acid gas as a fumigant for bulk grain is not possible for the average farmer at the present time. Its use is restricted to elevator concerns equipped with modern machin-

ery and able to employ technical assistance. The method of application is so involved that a full discussion is not given here. To the relatively few grain handlers who can use hydrocyanic-acid gas there is available in printed form an excellent article by Gilbert Schenk, reference to which will be given gladly.

The treatment consists, in brief, of thoroughly mixing calcium cyanide (in a fine granular form like medium fine sand) with the wheat throughout the bin. This is accomplished by installing a motor-driven hopper over the stream of wheat at a point close to where the wheat enters the bin. (Fig. 31.) By regulating the flow

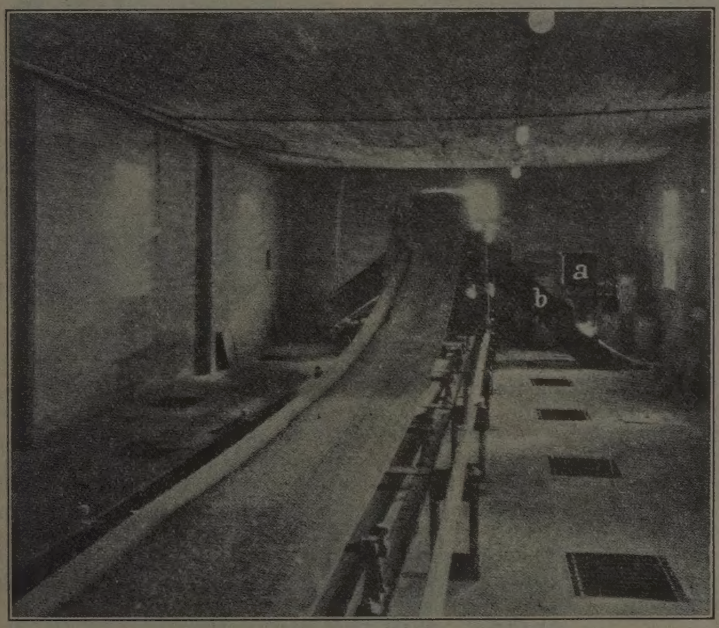

FIGURE 31.—The stream of wheat moving toward the tripper on the conveyor belt of a large grain elevator. Notice the small boxlike motor-driven hopper (*a*) which feeds the calcium cyanide to the stream of wheat as it passes down the chute (*b*) just before it enters the top of the elevator bin

of wheat and the discharge of calcium cyanide from the hopper into the wheat stream it is possible to incorporate with the wheat entering the bin a dosage of 25 pounds of the fumigant to each 1,000 bushels. Fumigations may be conducted with a temperature as low as 40° F. and should always continue for 72 hours. There is no fire or explosion hazard so far as the fumigant is concerned, and the long period of fumigation results in the death of all insects by hydrocyanic-acid gas, the vapor evolved from the calcium cyanide. It has been found by Swanson and Working [2] of the department of the milling industry of the Kansas State Agricultural College, that fumigations conducted with the recommended dosage of 25 pounds per

[2] SWANSON, C. O., and WORKING, E. B. HOW FUMIGATION AFFECTS WHEAT. The Millers' Review and Dixie Miller, vol. XC, no. 2, pp. 28–30, 1926.

1,000 bushels of wheat, or double this dosage, have no effect upon the milling or baking qualities of treated wheat. Also the experiments of these investigators indicate that the health of animals fed with grain treated with even double or treble the dosage recommended is not affected. Since hydrocyanic-acid gas is deadly to human beings, certain precautions against fatalities to workmen and operators must be considered. These precautions, however, are a part of any technical advice any firm deciding to use this fumigant must obtain from experienced fumigators and should be made a part of any contract entered into between an elevator concern and the fumigator employed.

ODORS FOLLOWING FUMIGATION

It is best that a fumigant should leave no odor on the grain that is not soon dissipated. Certain fumigants are impractical because they seriously taint the grain and the by-products made from it. Good grades of carbon disulphide and carbon tetrachloride will not leave an odor on grain that is objectionable to grain interests. The repeated use of a poor grade of either will sometimes so taint wheat that millers object to purchasing it. Grain that becomes soaked in carbon disulphide may retain a bad odor, but under usual conditions grain is not likely to become so saturated. The presence of other sulphur compounds is objectionable, because they may import an odor to the grain.

EFFECT OF FUMIGATION ON THE GERMINATION OF SEEDS

Careful experimental work has demonstrated that, with the exception of ethylene oxide, fumigations with the fumigants mentioned in this bulletin have no injurious effect upon the germination of seeds when conducted in the manner prescribed and at the strengths recommended. It is taken for granted that the seeds to be fumigated will be thoroughly matured and dry. Newly harvested corn, unless thoroughly mature and dry, can be killed by fumigation. The fumes of ethylene oxide have an injurious effect upon the germination of seeds, hence seeds intended for planting should not be treated with this gas.

HEATING GRAIN AND FUMIGATION

The heating of grain may be caused either by a high moisture content or by the presence of insects. Peas infested with bean weevils [3] have been known to heat to as high as 103° F. when the normal temperature was 58°. Wheat stored in farmers' bins and well infested with the rice weevil [4] and the flat grain beetle [5] has been found heating to 109° when the normal temperature was 27°. Wheat in shallow bins or on barn floors and stored in piles ranging in depth from 1 to 3 feet will heat if badly infested. (Figs. 32 to 34.) Wet corn stored in a concrete elevator bin has been known to heat to about 300°. Insects in heating grain are killed or driven away when the temperature approximates 120° or higher. The records of the grain inspection department of the Baltimore (Md.) Chamber of Commerce indicate that in 1923, during the September-December

[3] *Bruchus quadrimaculatus* Fab.
[4] *Sitophilus oryza* L.
[5] *Cryptolestes pusillus* Schön.

period, over 50 per cent of the 1,109 railroad box cars and bay boats fumigated because of insects present in the wheat shipped in them were recorded as heating.[6]

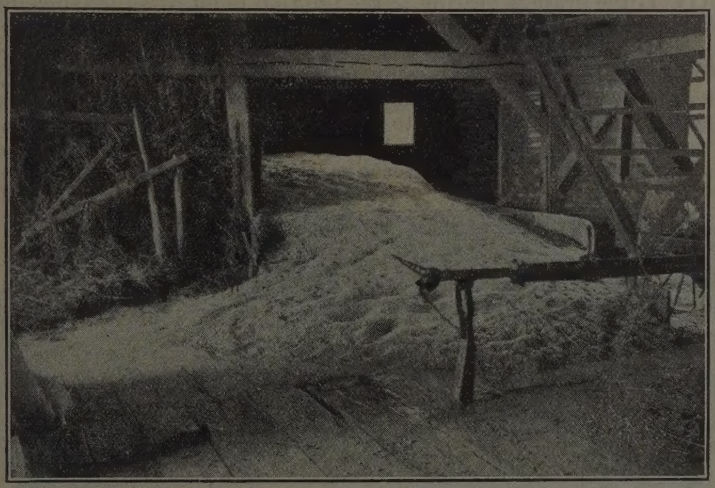

FIGURE 32.—On some farms wheat is stored, before sale to flour mills, on the barn floor as shown above. This is a condition favorable to insect increase, particularly in the case of the Angoumois grain moth. Such grain should be shoveled into as compact a space as possible and fumigated under a tarpaulin. This is a makeshift treatment to be recommended as a last resort

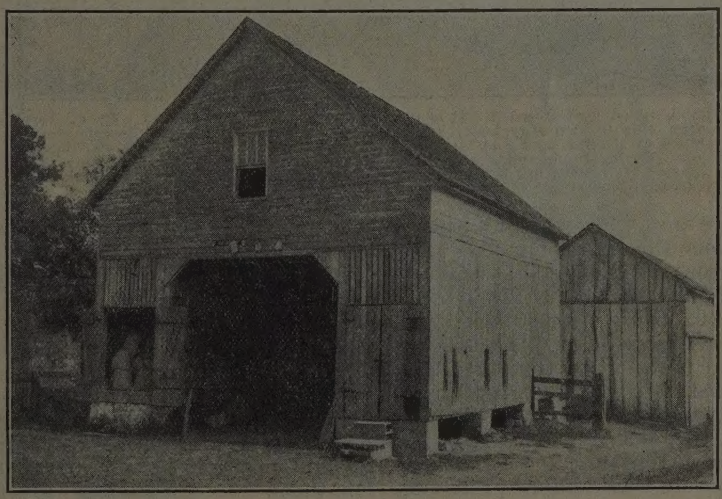

FIGURE 33.—A typical combination wagon shed, corncrib, and wheat bin common in the eastern wheat-growing region. The cribs on either side below may be slatted, and the wheat stored above. (See fig. 34)

[6] Data furnished the Bureau of Entomology by Harold Anderson, grain supervisor, Bureau of Agricultural Economics.

The foregoing facts are presented to direct attention to the following two important points that must be considered in fumigating hot grain:

(1) If the grain is heating to the ignition point of an inflammable and explosive fumigant, there is just as much danger of fire as though fire itself were brought in contact with the gas. There is on record only one instance of an explosion following the use of carbon disulphide in heating grain. In this case wet corn in a concrete bin was involved, and it was known to be heating, from causes other than insect attack, to a temperature of about 300° F.[7] When fumigating heating grain it should be determined beforehand that its tempera-

FIGURE 34.—Wheat stored in loft of farmer's shed shown in Figure 33. Wheat stored after this fashion may heat badly as a result of insect attack. Insects can be killed by making floor and bin sides tight and fumigating with a heavier-than-air gas. During fumigation grain should be covered with a tarpaulin or empty grain sacks. If the heating is caused by insects, fumigation will return the wheat to normal temperature

ture is well below the ignition point of the fumigant if the fumigant is one that is inflammable and explosive. The experience of fumigators the country over indicates that grain infested with weevils is seldom dangerously hot.

(2) Grain heating as a result of insect attack can have its temperature reduced to normal by fumigating with carbon disulphide, and probably by the other effective fumigants. If the outside temperature is low enough to prevent insects from feeding on grain the heating grain should be fumigated so that its temperature will fall to the normal. This will prevent insects from continuing their destruction during winter, when it would naturally be expected that the cold would afford protection from them.

[7] The spontaneous point of ignition of carbon disulphite is about 297° F.

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